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The announcement of the Research Program in Technologies for Metabolic Monitoring (DAMD17-BAA-TMM02) called for "new, novel and unconventional approaches to the field of metabolic monitoring". Given the significance of physical activity and energy expenditure (EE) to health for both military and civilian populations, we proposed a feasibility study to achieve the following goals: 1) to develop and validate non-invasive portable techniques in monitoring detailed physical activity and accurately predict EE, and 2) to determine specific physical training related energy costs and physiological responses in ROTC cadets. The novel methodology we used for this study was an accelerometry array portable monitor we developed collaboratively with a small startup company (Minisun LLC). We designed a two-stage data collection periods, expanding one academic year (Fall-Spring). Despite several delays and problems encountered, we have completed the major components of the studies we had proposed. We demonstrated the accuracy of this instrument in predicting EE in the ROTC cadets in well-controlled laboratory environments while performing various exercises, suggesting its great potentials to be a tool for the detailed assessments of physical activity, energy metabolism, and physiological responses for various applications in the military and general populations. However, practical improvements, such as a developing a suit with build-in sensors and wires, and analytical prediction model optimizations should be our next steps to guide the future technical advancements.

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INTRODUCTION

This proposed study was in response to the specific call from the US Army Medical Research and Materiel Command (MRMC) for Technology of Metabolic Monitoring program (**DAMD-BAA-TMM02**), in which research projects were solicited to "*identify and assess technologies that can improve our ability to collect and interpret metabolic data ... and to use that data to extend our understanding of human metabolism in healthy, diseased, and stressed states*". The predominant contributor to a person's energy metabolism is physical activity. However, current knowledge in physical activity and its contribution to the health and diseases of humans is limited. This is mostly due to limited technology for the accurate and detailed measurement of the highly variable nature of human physical activity, and more, importantly its related energy expenditure (EE). Our research expertise and environment position us in an inimitable position for developing and validating portable devices for EE measurement in humans. In this study, we propose to develop a **novel** and **non-invasive** approach for accurately determining the detailed metabolic demands in ROTC cadets during physical training (PT). This study will establish close collaborations between clinical researchers and biomedical engineers in advancing the technologies of portable metabolic monitoring, which are essential in determining the unique relationships between energy balance and health for military personnel [1] as well as the greater general public. Working in close collaboration with the Vanderbilt University Army ROTC program, we will further investigate the physiological demands during PT, while setting long-term goals to optimize soldiers' health, fitness, and conditioning.

BODY

The approved specific tasks for this project are:

1. to ascertain simultaneous physical movement data from a new activity/posture monitor and EE data from our room calorimeter
2. to establish accurate models of prediction EE from the body motion parameters
3. to validate the accuracy and reproducibility of the models with gold-standard techniques under field conditions
4. to assess nutritional, fitness, and other physiological measures prospectively.

The approved schedule is as the following:

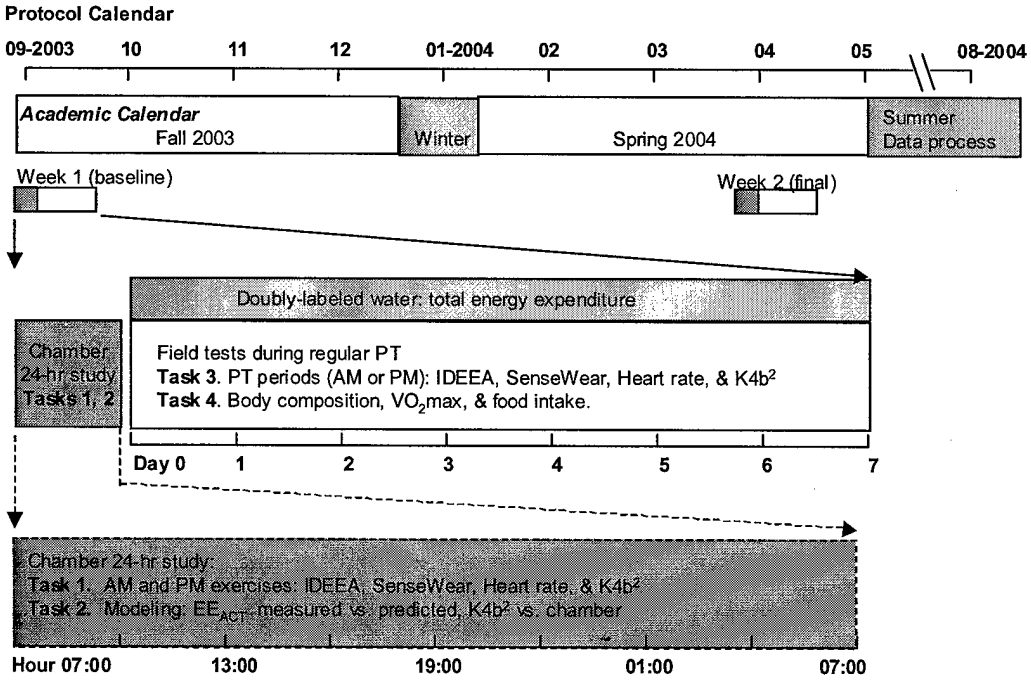

Figure 1. Approved study design and timeline.

Research Methods

Portable Monitors: Three monitors (Figure 2) were used to measure movements of activity and predict the EE of activity (EE_{ACT}) from the manufacturer-specified equations. These three monitors, the RT3, SenseWear, and IDEEA monitors, uniquely represent the three generations of currently available physical activity (PA) monitors – single sensor/single site, multi sensor/single site, and multi sensor/multi site, respectively.

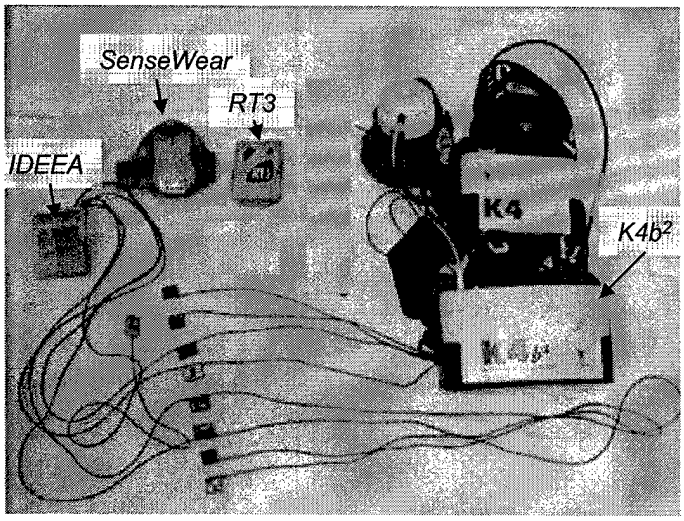

Figure 2. Portable physical activity monitors and the portable calorimeter ($K4b^2$) that were used for this study

RT3 Research Tracker (Stayhealthy Inc., Monrovia CA) is a triaxial accelerometer device. It is the size of a pager (71x56x28 mm and weighs 65g with one AAA size battery) and is worn clipped onto the **hip**. It uses piezo-electric accelerometers and measures motion in three orthogonal dimensions and provides tri-axial vector data in activity units (counts). The sensor range, data sampling frequency, and A/D converting resolution are proprietary. The manufacture's software calculates a subject's EE_{ACT} using the vector magnitude of the activity counts and a linear regression algorithm, which is also proprietary. The RT3 is capable of collecting and storing data up to 8.5 days (triaxial mode) with a battery life of 30 days. We have used this monitor extensively in adults and children. [2-4]

SenseWear Armband (Bodymedia Inc., Pittsburgh PA) is a relatively new monitor (85x54x20 mm, 85g with an internal lithium-ion battery) which is contoured to be worn at the **upper arm**. The internal sensors include an accelerometry sensor, heat flux sensor, galvanic skin response sensor, skin temperature sensor and a near-body ambient temperature sensor. The accelerometer in the armband is a 2-axis accelerometer that utilizes a micro-electro-mechanical sensor device that measures motion. A poly-silicon spring supports a small mass that moves when subjected to external acceleration, i.e., body movements. The scale for the sensor is ±2 G with an 8-bit A/D converter (256 counts at 3.66 mg/count). The sampling rate is 32 Hz and has 512KB RAM of data storage. The manufacture's software calculates a subject's EE_{ACT} using a proprietary algorithm that combines acceleration, heat flux and other parameters. The SenseWear is capable of collecting and storing data up to 5.5 days at 1-minute epoch.

Intelligent Device for Energy Expenditure and Activity (IDEEA, MiniSun LLC, Fresno CA) is being developed in close collaboration between our lab and its manufacturer. The IDEEA utilizes continuous movement data from five miniature motion sensors (2x1.5x0.4 cm^3, size of a thumb nail, weighing <1 gram) attached at the **sternum, mid thigh of both legs,** and both **feet** with hypo-allergic tape via 3 thin and flexible wired (outside diameter=2mm) and sends input to the minicomputer (10x5x2 cm^3, weighing 200 g) clipped at the waist belt. A total of 48 hours of continuous raw data (>100 megabytes) can be stored in the IDEEA computer for analysis. The types of physical activities can be accurately determined using artificial neural network and other advanced modeling techniques. The special software that we have developed provides a powerful tool for in-depth study of the essential characteristics of physical activity: type, intensity, frequency, and duration. Currently, we can detect over 44 basic activity types including basically all daily activities with extremely high precision (>97%).[5] To our knowledge, IDEEA is the only available technique that could detect detailed postures and physical movements and their onset, duration, frequency, and intensity such as the speed of locomotion and mechanical power generated. However, additional models need to be developed and validated systematically to convert these activities into EE according to the type and intensity of these activities and individual variations in weight, height, and gender. The reproducibility also needs to be confirmed.

CALORIMETERS

Whole-room indirect calorimeter

The ability to accurately measure continuous EE_{ACT} is crucial. We used the unique and state-of-the-art *Activity-Energy Measurement System* that we have designed and developed in the last decade at Vanderbilt for validation of the portable PA monitors under well-controlled laboratory conditions. This high-precision and multiple-functional system consists of: 1) an open-circuit whole-room indirect calorimeter that has highest accuracy and fastest response time, 2) large force platform for the accurate quantification of external mechanical work during daily PA and exercise, and 3) a sensor/monitoring system for determining PA types and patterns in the calorimeter.

The **whole-room indirect calorimeter** is a small, airtight environmental room (2.6 x 3.4 x 2.4 m, 19,500 liters in net air volume) with an entrance door (1 x 2 m) and an air lock (0.6 x 0.3 m) for passing food and other items. The room is equipped with a desk, a chair, an outside window, a toilet, a sink, a telephone, a TV/VCR, an audio system/alarm clock, and a fold-down mattress. Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) are calculated by measuring the changes of oxygen and carbon dioxide content of the air inside the calorimeter and by the flow rate of the purged air times its concentration of gases. A special multi-channel air sampling system was designed to ensure an even sampling of the gas expired by the subject. Temperature is precisely controlled, while barometric pressure and humidity of the room are monitored. For this proposed investigation, the sensitivity of the system (response time) is very important because EE change in minutes in response to body movement during PA. Our system can consistently achieve the highest accuracy and fastest response time (>90% recovery in 1 min) compared to other room calorimeter units that are similar in size.[6] To our knowledge, these are the most accurate data ever reported using whole room indirect calorimeters with measurement intervals as short as 1 minute. The accuracy and fast response of this whole-room indirect calorimeter make it possible to study EE_{ACT} in details that were not feasible previously. Figure 3 illustrates a few types of PA that are commonly performed in the room calorimeter.

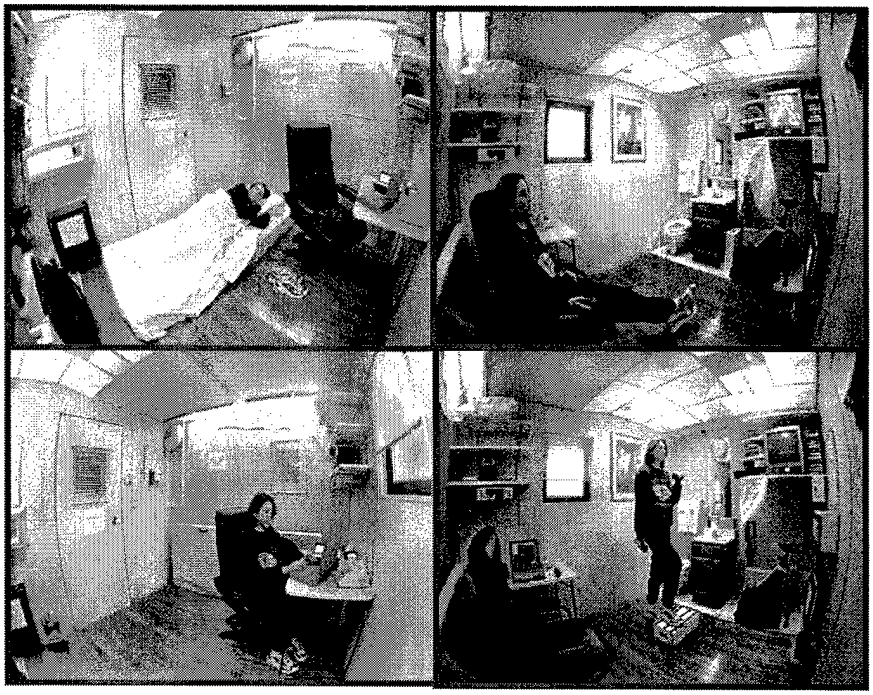

Figure 3. A subject performs various PA's in our whole-room indirect calorimeter.

A precision large force platform can be used to quantify PA, in terms of body movement, speed, acceleration, and the mechanical work (MW) performed. The platform is supported by multiple precision force transducers and covers the total living area inside the room (2.5 x 2.5 m). Its sensitivity ranges from 20 grams to 900 kilograms, with a guaranteed error of less than 0.008% of full scale. This enables us to study a wide range of PA (sedentary and vigorous) with great accuracy. Forces, movements, and MW components (vertical and horizontal) are sensed by the transducers and interfaced with a computer and calculated in real time, simultaneously with the minute-by-minute EE measurement. The computer calculates the above criteria 60 times per second and stores the results at 10-second intervals over 24 hours.[7]

The behavioral sensing and monitoring system inside the calorimeter consists of an electronic monitoring system that can detect behavior patterns on a 24-hr basis. These include: a) duration and frequency of television watching, b) starting and ending time of each sitting period during the day, c) distance a subject moved during any given period (ranging from 10 seconds to 24 hours or longer), d) sleeping and awake time as

well as the total duration of sleep, e) the intensity and duration of each exercise period the subject performed using exercise equipment (e.g., the cycle ergometer, treadmill, or the step box inside the room), and f) the duration and frequency of meals.[6]

Portable indirect calorimeter

We used the K4b^2 device (figure 2) **to measure EE of those PA's that could not be performed inside the room calorimeter, such as during the PT.** The **K4b^2** (Cosmed, Inc., Rome, Italy) is the new generation of portable indirect calorimeters, an alternative to the metabolic carts that allows measurements of EE in the field-environment. It consists of a lightweight and flexible facemask (difference sizes for appropriate fit, 300g) and a portable analyzing unit (170x50x100 mm, 475g), which can be strapped at the back or waist. The system allows breath-by-breath gas exchange measurements for up-to 16,000 breaths before downloading the data to a computer. Using a cycle ergometry, McLaughlin and colleagues reported the accuracy of K4b^2 (compared to the Douglas bag method) ranged from 9.6% at 50 Watts to 3% at 200 Watts for measuring EE.[8] To our knowledge, this device is the only validated portable indirect calorimeter which measures both O_2 consumption and CO_2 production.

Protocol

The schedule for the indirect calorimetry room (24-h study):

07:00 AM	Come to GCRC for vital signs
08:00 AM	Enter Calorimetry room, begin test
08:00-08:30 AM	Sitting and resting
08:30-09:00 AM	Breakfast
09:00-09:30 AM	Free time
09:30-09:40 AM	Level walking on treadmill at (2-4 miles/hour), no load
09:40-09:50 AM	Sitting and resting
09:50-10:00 AM	Level walking at 2.5 miles/hour, no load
10:10-10:20 AM	Sitting and resting
10:20-10:30 AM	Level walking at 3.5 miles/hour, no load
10:30-10:40 AM	Sitting and resting
10:40-10:50 AM	Sit/stand alternating per 5 second interval
10:50-11:00 AM	Sitting and resting
11:00-11:10 AM	Level walking at 3 miles/hour, 20lb backpack load
11:10-11:20 AM	Sitting and resting
11:20-11:30 AM	Jog at a comfortable pace (5.5-7 miles/hr), no load
11:30-11:40 AM	Sitting and resting
11:40-12:30 PM	Free time
12:30-01:30 PM	Lunch
01:30-02:30 PM	Free time
02:30-03:00 PM	Walk at 5% incline, 3.5 miles/hour, 10lb backpack load
03:00-05:00 PM	Free time
05:00-05:30 PM	Supper
05:30-09:30 PM	Free time
09:30 PM	Go to bed
06:00-06:30 AM	Wake up/ resting energy expenditure (resting EE)
06:30-07:00 AM	Sitting and resting
07:00-07:30 AM	Exit Calorimetry room

Results:

Participant Identification, Inclusion/Exclusion Criteria, and Recruitment

As originally proposed, volunteers from the Vanderbilt University ROTC cadets were targets as study participants. The Principle Investigator (Dr. Chen) and his research coordinator (Megan Neumann, RD) first identified candidates who may be interested in participating in this study. Before official recruiting, we conducted an orientation session during one of the Lab sessions to introduce this study to all ROTC cadets. Interested cadets will then be contacted by our research coordinator for screening information and possible recruitment. If the subject qualified and was willing to participate, a study visit will be scheduled at that time.

Inclusion: healthy ROTC cadets, males and females, between ages 18-25 years

Exclusion: pregnant women, diabetics, subjects unable to give voluntary informed consent, subjects with metal implants, subjects with a recent (within 1 year) medical illness (conditions that may affect their metabolism or ability to perform the tasks of PT), subjects with known liver, thyroid, or kidney disease, subjects with past history of hypertension, heart disease, or cerebrovascular incidents, subjects with recent weight change (±2 kg in the last year) or on a very low calorie diet (<1500 kcal/d), subjects taking medication that has known effects on energy metabolism, and subjects with orthopedic problems.

Subject Characteristics: 12 cadets (10 males and 2 females; 8 Caucasians, 2 African-American, 1 Asian, and 1 other) were consented. The general characteristics are shown in Table 1:

	Mean ± SD	*Range*
Body mass (kg)	79.2 ± 13.8	60.3 – 100.0
Height (cm)	176.4 ± 8.23	158.0 – 188.0
Age (yrs)	19.8 ± 1.0	18 – 21
Body Composition (%fat)	17.5 ± 7.2	7.1 – 31.2
VO_2max (ml O2 / kg · min)	53.8 ± 8.0	43.0 – 69.5

Timeline:

1. Original proposal was submitted in July 2nd, 2002.
2. Grant awarded in October 1st, 2002.
3. We received the Surgeon General's Army Human Subjects Research Review Board (HSRRB) approval in July 10th, 2003.
4. Studies began in September, 2003.
5. For week 1 (the initial phases), we collected eleven (11) 24-hour period data by November 23rd, 2003.
6. For week 2 (the final phase), we collected five repeated cadets (from the original 11) and one new cadet's 24-hour period data by April 24th, 2004.

Tasks 1-2: Validations of PA monitors against the gold-standard (room calorimeter) under laboratory conditions

When the data from each of the three monitors were synchronized with measured EE data ascertained from the room calorimeter, we first assessed the prediction accuracy for each test by the following measures:

1) total EE: the minute-to-minute EE integrated over the entire study period and extrapolated to 24 hours (the actual study period was 1335 ± 23 minutes, or 22.3 ± 0.4 hrs)
2) Pearson's R: correlation coefficient of the measured vs. predicted EE (minute-to-minute) for the study period

3) Standard Error of Estimation (SEE): standard deviation of the difference between measured and the predicted EE (minute-to-minute) for the study period.

Figure 4 showed a typical example of the EE data ascertained from the room calorimeter (thick blue line) as it was compared to the three portable PA monitors (thin colored lines) used in this study.

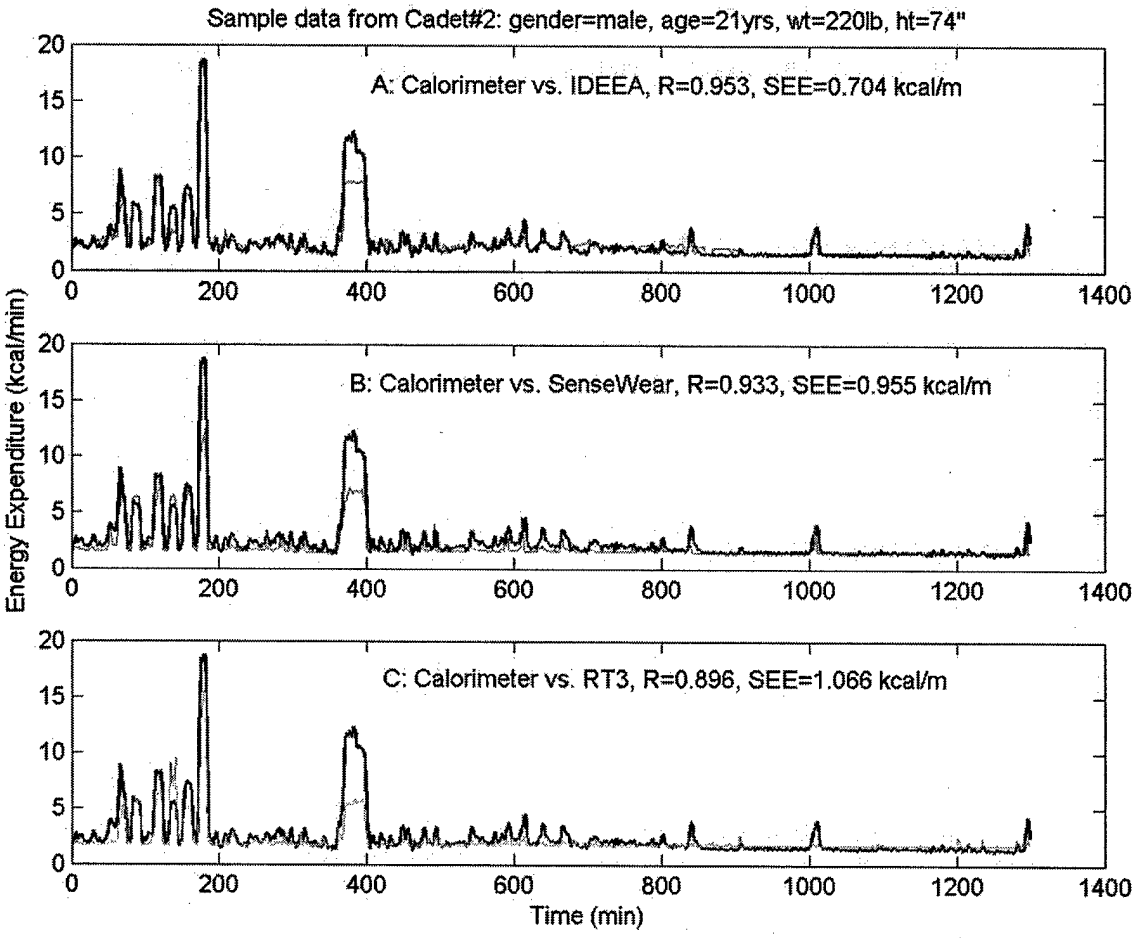

Figure 4. An example of one data set from the Room calorimeter vs. IDEEA (A), SenseWear (B), and RT3 (C) output

From Figure 4, one could observe the general correlation between the measured and predicted EE were excellent; however, it was also evident that there were incidences of both over and under predictions of EE_{ACT} by the activity monitors compared to the gold-standard (room calorimeter).

When analyzed as a group, the data revealed that total EE predicted by the IDEEA monitor was the closest to the measured total EE for the group (100.4±4.1%, P=0.936), and its R was the highest (0.933±0.018) and the SEE was the lowest (0.614±0.131 kcal/min). The detailed group results are shown in Table 2:

	Total Energy Expenditure (Kcal/min)				Pearson's R (vs. Calorimeter)			Standard Error of Estimation		
ID	*Calorimeter*	*IDEEA*	*RT3*	*SenseWear*	*IDEEA*	*RT3*	*SenseWear*	*IDEEA*	*RT3*	*SenseWear*
1	2721	2680	2551	2377	0.933	0.934	0.885	0.532	0.742	0.690
2	3613	3559	3121	2956	0.953	0.896	0.933	0.704	1.066	0.955
3	3260	3279	2944	2907	0.942	0.916	0.947	0.682	0.822	0.758
4	3717	3368	3339	3101	0.945	0.930	0.928	0.743	0.831	0.885
5	2986	3050	2555	2877	0.937	0.915	0.824	0.622	0.753	0.986
6	2299	2425	2117	1969	0.940	0.937	0.959	0.543	0.450	0.411
7	2548	2659	2232	2234	0.908	0.943	0.932	0.597	0.621	0.520

8	2799	2814	2902	2701	0.953	0.942	0.932	0.497	0.833	0.629
9	3139	3202	2582	2700	0.898	0.923	0.947	0.921	0.783	0.722
10	2327	2297	2295	1936	0.946	0.950	0.957	0.448	0.500	0.504
11	2638	2575	2263	2230	0.911	0.925	0.934	0.530	0.556	0.463
12	3092	3265	3212	2950	0.929	0.920	0.904	0.547	0.884	0.647
Mean	**2928**	**2931**	**2676**	**2578**	**0.933**	**0.928**	**0.923**	**0.614**	**0.737**	**0.681**
SD	460	409	417	410	0.018	0.015	0.038	0.131	0.177	0.190
Min	2299	2297	2117	1936	0.898	0.896	0.824	0.448	0.450	0.411
Max	3717	3559	3339	3101	0.953	0.950	0.959	0.921	1.066	0.986

Compared to the measured values, total EE was significantly (paired t-test) underestimated by RT3 (P=0.002) and SenseWear (P<0.001), but not for IDEEA (P=0.0936); although the R values (with respect to calorimeter) for the IDEEA was not significantly higher than RT3 (P=0.456) or SenseWear (P=0.453), the SEE for IDEEA was significantly lower than RT3 (P=0.025) and slightly lower than SenseWear (P=0.181). Also, all three portable monitors significantly (P>0.01) underestimated EE_{ACT} during loaded walking.

Task 3: Validations of PA monitors against the gold-standard ($K4b^2$) in field conditions

Figure 5 shows three cadets being field-tested. In contrast to the Tasks 1-2, we experienced considerable difficulties in completing this specific task. We were able to ascertain only five sets of complete data during 1-hour physical training (PT) sessions using the IDEEA, SenseWear, RT3, and $K4b^2$. We summarized the reasons for our lack of success in the **Problems Encountered section**.

Figure 5. Posing after the field test during PT.

Task 4: Assessments of nutritional, fitness, and other physiological measures

All subject characteristics, including body weight, height, age, body composition, and fitness levels were assessed in the cadets, both during phases 1 and 2. Body weight was measured to 0.1 kg using a digital scale (which was calibrated using a standard mass weekly). Height was measured to 0.5 cm using a wall-mounted statiometer. Body composition (%fat) was measured using our research dual-energy x-ray absorptiometry (DEXA) scanner (LUNAR Prodigy, GE Medical Systems, Madison, WI). This system determines body fat, lean (muscle), and bone masses by producing a full-body scan via photons at two different energy levels, 40 and 70 KeV. The photons pass through tissues and attenuate at rates related to elemental composition. Bone mineral, with highly attenuating calcium and phosphorous, is readily distinguished from soft tissues. The different elemental profiles of fat and bone-mineral free lean allows for the analysis of soft tissue fat content, so that bone mineral, fat, and bone mineral fat-free lean components may be resolved. DEXA is considered as the gold-standard in total body composition measurements. We measured fitness levels (VO_2max) using standard Bruce protocol. The procedure involves measuring oxygen consumption using a metabolic cart (MedGraphics® *CPX/D* System, Medical Graphics Inc, St. Paul, MN) during walking/running on a treadmill. A specially constructed treadmill was used for all the tests, performed by the study coordinator (Ms. Neumann) to minimize tester error. The Bruce protocol was used for all of the subjects. The physician monitor (Dr. Acra) was present during all the tests. Table 3 shows the prospective data:

	Phase 1 *(mean ± SD)*	*Phase 2* *(mean ± SD)*
Body mass (kg)	79.2 ± 13.8	80.2 ± 12.5
Height (cm)	176.4 ± 8.2	176.9 ± 9.5
Age (yrs)	19.8 ± 1.0	20.7 ± 1.1
Body Composition (%fat)	17.5 ± 7.2	20.4 ± 7.9
VO_2max (ml O2 / kg · min)	53.8 ± 8.0	51.1 ± 7.1

Although none of these parameters changed significantly (except for age, as expected) statistically ($P>0.05$), the tendency of a corelational trend between an increase in body weight and %fat and a decrease of fitness level should be noted. We suspect that the reason for such changes was due to the fact that during phase 1, the cadets were actively participating in the "Ranger Challenge" training for which the intensity and duration of PT were approximately doubled compared to the PT training for phase 2. This, however, demonstrated the correlation between training, body weight, body composition, and fitness level in these ROTC cadets.

Problems encountered:

1) Delay of testing cycle: due to the actual funding did not start until October 2002, our original proposed testing cycle (with academic year) had to be change to 1 year later. This was approved.
2) Acquiring doubly-labeled water (DLW): although we started the process of finding suppliers immediately after we received grant approval, we did not get the isotopes in time for validation of free-living physical activities because of global supply shortages.
3) Since our test instruments are not waterproof, several of all field trials were postponed due to weather.
4) Our original proposal of field trials was designed to be conducted in the afternoon PT sessions. However, starting the Fall 2003 semester, all Vanderbilt Army ROTC PT sessions were changed to 0600-0700 AM. Since it takes about 20 minutes to equip each test subject with all the test instruments, the demands on testing cadets to be in the field about 1 hour earlier (3-4 trials conducted simultaneously, as approved) has been somewhat challenging.
5) We have also encountered considerable incomplete collections (3 from the $K4b^2$, 1 from the IDEEA, and 3 from the SenseWear) during these field trials (total of 8 trails involving 17 cadets), of which some were due to operational errors in the darkness, and others were due to equipment failure. Furthermore, we did not anticipate the fact the $K4b^2$ has a humidity range of 25-85%; while all but one test had a humidity level less

than 85%. We are currently working with the manufacturer to correct the EE readings post-hoc. Thus, the results for the field tests were not reported.

6) We also encountered a number of drop-outs from phase 1 to phase 2 for task 1. The reasons for such unanticipated high number were due to two drop-outs from the ROTC program, changing in PT curriculum (from Fall 03 to Fall 04), and the fact that a number of the ROTC cadets caught the flu during that period, which were all unrelated to the study.

Key Research Accomplishments

To our knowledge, this was **the first study that explored the use of the raw acceleration components from a sensor-array PA monitor for EE_{ACT} prediction**. The major advantage of this new approach is apparent: it would provide PA types, such as sitting, standing, walking, and jogging, together with the dynamic change of body motions for the improvement of EE_{ACT} prediction. However, our results also demonstrated that for different PA types and intensities, the accuracy of the IDEEA predictions varied. For most of the time, the underestimations occurred noticeably during periods of resting when spontaneous movements (presumably by the upper body) were undetected by the sensors of the IDEEA monitor. Conversely, the current (generalized) prediction model also overestimated several PA bouts of walking and jogging for the Cadets. In fact, it accurately predicted EE_{ACT} for jogging (-1.9±3.4%, P=0.62) but it significantly overestimated EE_{ACT} during walking (9.6±7.5%, P<0.05) for the whole group. The prediction accuracy was not significant different between the speed (P=0.43) for the group. The major limitation of the current IDEEA device is that, other than the chest monitor for postural determination, it does not include upper body sensors for the assessment of movement of the arms and hands. This could be a major cause for EE_{ACT} underestimations during sedentary PA.

To extend the concept of modeling EE_{ACT} by using the raw acceleration signals to the whole body, we need to refine the IDEEA device to add signals from the upper limbs. Furthermore, several market-

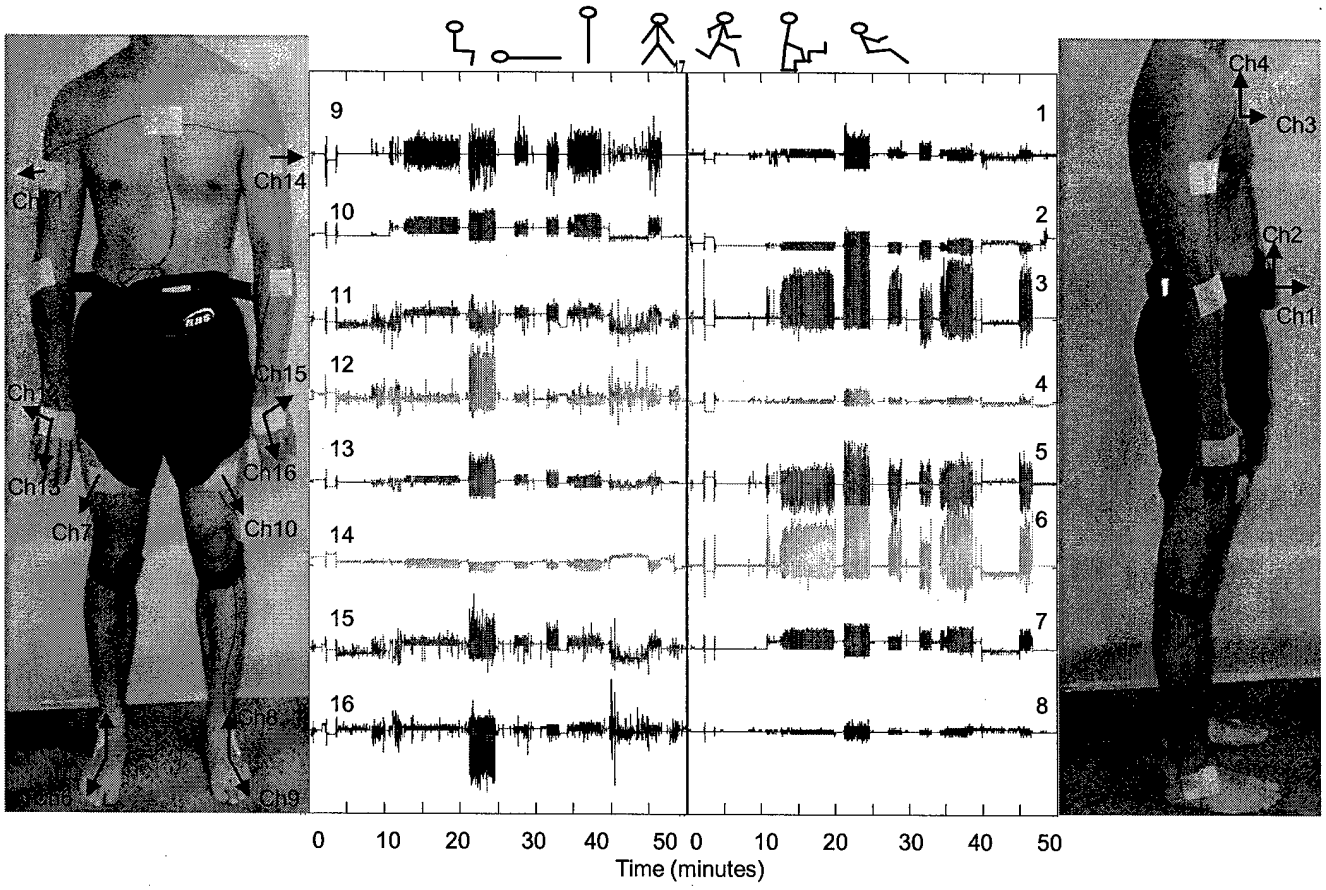

Figure 6. The custom-designed IDEEA 2 monitor (10 sensors) is applied to a volunteer. Hypo-allergenic tape (white) is used to attach the sensors to the skin. A set of 16 synchronous data channels collected raw acceleration signals at 32 samples/second for a 50-minute testing period that included various PA's.

available PA monitors are worn at the hip, due to the close proximity with the center of mass. In order to explore the raw signals from the hip, we also need to add a sensor in the device. Using the technical flexibility of the IDEEA concept and data collected in this study, we recently custom-designed a prototype device (*denoted **IDEEA2 monitor***) by adding sensors to measure movements of both arms, both hands, and the hip. The new anatomical sites, in addition to the lower limbs and the chest sites described in the previous study, are the lateral surfaces of the upper arms (just below the deltoid muscles) and middle of the 3rd metatarsals on the back of the hands (aligned with the directions of the metatarsals). Figure 6 demonstrates the locations of each sensor and the directions of their acceleration axes. In addition, we also added a bi-axial accelerometer inside of the collection minicomputer that is worn at the hip. For system consistency, the five added sensors in the IDEEA2 monitor for the upper limbs and hip are identical to the ones in the existing IDEEA device for the lower limbs and chest.

Similar to the original IDEEA monitor used in this study, we will collect raw acceleration signals at 32Hz and stored them in the IDEEA 2 device with 16 channels of data arrays (doubling the data input). As the middle graphs from Figure 6 demonstrated, we have successfully proven the **feasibility** of collecting raw data during PA's such as sitting (with and without upper limb movements), lying supine, driving a car, standing (with or without upper body movements), sweeping the floor, standing and moving arms, walking, jogging, and climbing up and down the stairs.

Reportable Outcomes

1. **Chen KY**, Acra SA, Majchrzak KM, Baker L, Donahue CL, Clement L, Sun M, Buchowski MS. Predicting Energy Expenditure of Physical Activity Using Hip and Wrist Worn Accelerometers. *Diabetes Technology & Therapeutics*, 2003; 5(6): 1023-1033.
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Future directions:

1. To explore the data from these studies and produce peer-reviewed manuscripts.
2. To further develop the hardware and prediction models for IDEEA2 monitor (with sensors for upper-body segments).
3. To include the physiological measurements (heart rate and body temperature) to the PA monitoring.
4. To design and test a suit to include these sensor to minimize application time and variabilities.
5. To comprehensively test the suit under laboratory and field conditions.

Conclusions

- This study should initiate the crucial steps towards fundamental changes in the development of field techniques to accurately measure detailed physical activity and EE_{ACT}.
- The results of this research should also lead to larger studies to better evaluate the physical and physiological demands involved in physical trainings in military personnel.
- The applications of these devices in the field need further modifications.

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